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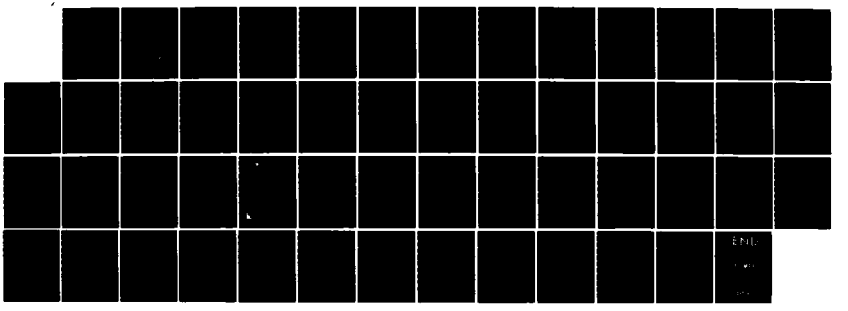

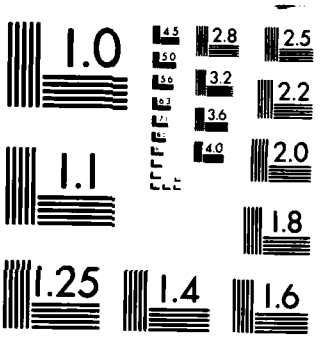

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ANALYSIS OF RADIATION EXPOSURE, THIRD MARINE CORPS PROVISIONAL ATOMIC EXERCISE BRIGADE

Exercise Desert Rock VI, Operation Teapot

Science Applications, Inc
P.O. Box 1303
McLean, VA 22102-1303

15 February 1984

Technical Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The radiation dose is reconstructed for 3d MCPAEB personnel participating in exercises involving helicopter lifted assaults in conjunction with Shot Bee of Operation Teapot, Exercise Desert Rock VI. Brigade personnel were exposed to initial radiation while in trenches at the time of the Shot Bee detonation. They were also exposed to residual radiation from an earlier test shot (Shot Turk) during their subsequent maneuvers and to residual radiation from Shot Bee during an inspection of equipment displays. The calculated total gamma doses to the bulk of the participating troops range from about 0.57-0.85 rem.

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Section 1
INTRODUCTION AND SUMMARY

This report presents an analysis of nuclear radiation exposure for personnel of the Third Marine Corps Provisional Atomic Exercise Brigade (3d MCPAEB) during their participation in Exercise Desert Rock VI (Operation Teapot) at the Nevada Test Site in the spring of 1955. The exercise, controlled by command and staff elements of the 3d MCPAEB, took place over a period of two weeks. During this period, the marines trained, rehearsed, observed the nuclear burst designated Shot BEE, conducted post-shot maneuvers, and viewed the effects of the burst on typical military equipment.

The activities of the brigade are examined for the two weeks spent at Camp Desert Rock in March 1955. Although there was general participation in only Shot BEE the residual radiation from pertinent previous bursts in Operation Teapot is also examined to determine the total dose contribution to the marines during all of their activities. Figure 1 shows the location of the ground zero (GZ) of Shot BEE and the other pertinent shots in the Teapot Series. Time-dependent position information is determined and presented in order that a complete exposure analysis can be performed. External dose is reconstructed and the associated uncertainties are identified and calculated.

Several documents are available from which to reconstruct events, times, and activities in sufficient detail to facilitate meaningful analysis. The principal documents used for this report are References 1 through 4. They describe the planned and actual operations for the maneuver elements and related activities of other units, such as the troop observers for Exercise Desert Rock VI. Collectively, these documents present an essentially complete picture of the 3d MCPAEB activities. They are supplemented by military judgement for some of the unstated details necessary for exposure analysis.

As indicated in Section 2 of this report, the marine brigade operations conducted at Shot BEE were quite complex. However, with the exception of the post-maneuver walk-through and inspection of the display area, they were all conducted at distances greater than 3.5 miles (5.6 kilometers) to the west or south of the 8 kiloton detonation.

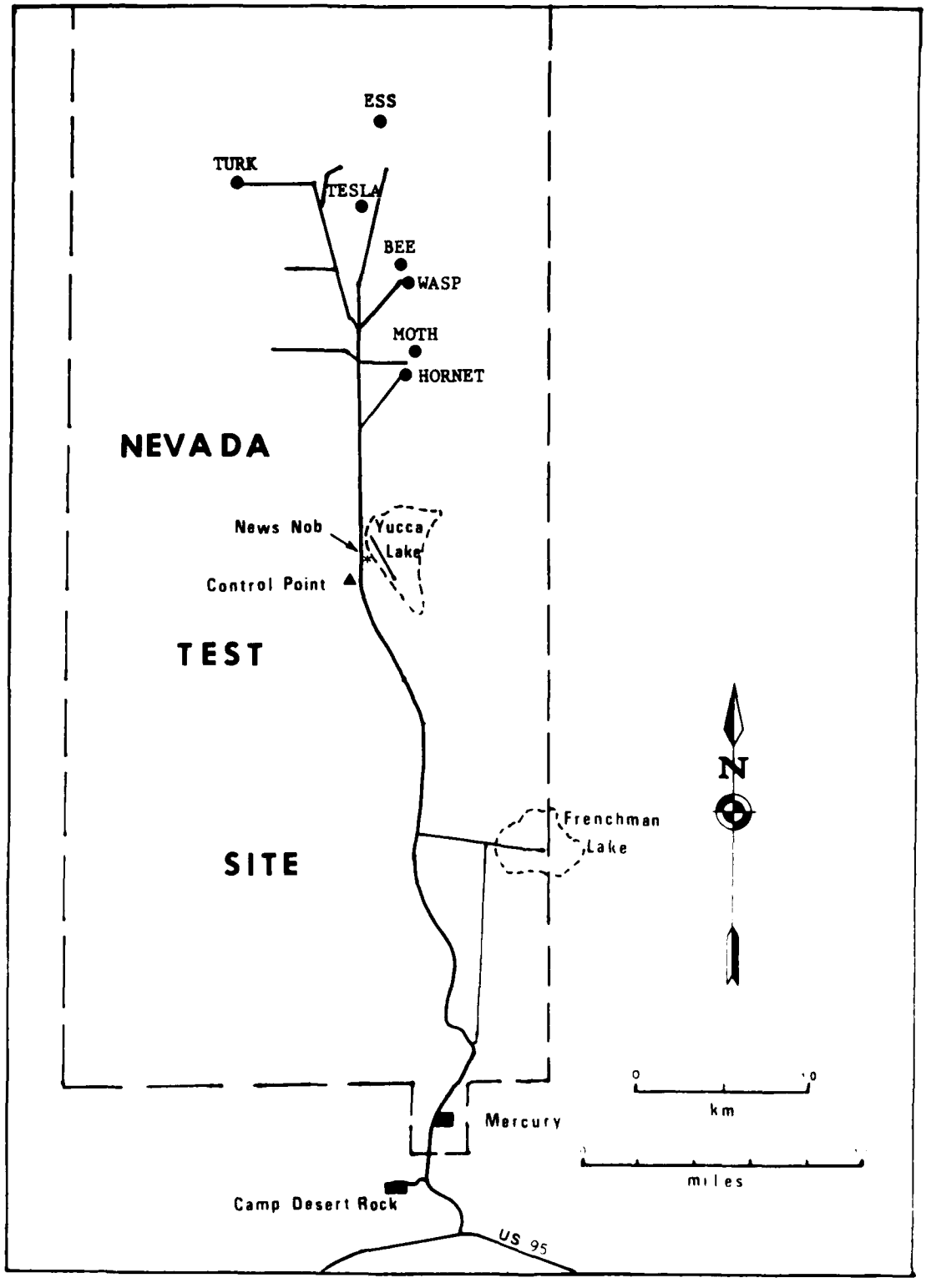

Figure 1. Operation TEAPOT, Selected Shot Locations

The surveys show that, except for the area within 1.5 miles (2.4 kilometers) of GZ, the residual radiation pattern was predominately to the east. Therefore, the main brigade activities involved no calculable level of exposure to Shot BEE residual radiation. The post-maneuver inspection of the display area by the bulk of the 3d MCPAEB did involve some exposure to residual radiation at the display lines nearest to ground zero. The combination of data from the periodic post-shot radiological surveys and the rad-safe data reported by the marines and by other Desert Rock VI participants proved sufficient for a satisfactory reconstruction of the dose to all of the major elements of the marine brigade. Reasonable bounding constraints on the troop activities and the radiological environment form the basis for an uncertainty analysis.

Important data for this exercise include detailed film badge dosimetry records. Although film badges were not issued to all participating personnel, dose records for about 25 percent of the 3d MCPAEB are available. These data are used to verify the calculations as well as some of the details of brigade activities.

Major findings of this report are:

- The radiation exposure to troops of the 3d MCPAEB was due almost entirely to residual radiation from Shot BEE and was primarily incurred during inspections of the exhibits on the display lines closest to GZ..

- The calculated gamma dose for the bulk of the maneuver troops is $0.57^{+0.35}_{-0.27}$ rem. This compares favorably with film badge records for about 25 percent of the brigade personnel which show an average film badge dose of 0.41 rem for the maneuver troops. There are seven film badge readings of higher doses (0.65 - 0.87 rem). These correlate with the range of the observer doses in the records. These readings may be representative of a contingent of the 3d MCPAEB Camp Detachment that accompanied the observers at Shot BEE.

Brigade elements began departing Camp Desert Rock on 23 March. The main elements of the brigade arrived at their home bases in California on 25 March, with the Camp Detachment returning on 31 March.

Section 2
OPERATIONS

Shot BEE was the sixth in a series of fifteen nuclear weapon test shots comprising Operation TEAPOT at the Nevada Test Site during the spring of 1955. A military exercise involving the 3d MCPAEB was conducted in conjunction with Shot BEE. This exercise was part of Exercise Desert Rock VI, the overall designation for military exercises conducted during Operation Teapot.

2.1 SHOT DATA (References 3, 4)

Date/Time:	22 March 1955, 0505 hours, Pacific Standard Time
Location:	Area T-7 (Ia); Nevada Test Site, UTM Coordinates 867056 (Figure 1-1)
Yield:	8 kilotons
Height of Burst:	500 feet (steel tower)

2.2 PARTICIPANTS

The troops participating in the Shot BEE exercise consisted of the 3d MCPAEB. The brigade, formed for the purpose of conducting the U.S. Marine Corps portion of Exercise Desert Rock VI, comprised 299 officers and 1972 enlisted men (total 2271 personnel) organized as follows (Reference 3):

3d Marine Corps Provisional Atomic Exercise Brigade

Headquarters and Service Company (H&S Co), MCTU #1
Headquarters and Service Company (H&S Co), 1st Battalion
Marine Camp Detachment, Camp Desert Rock
1st Battalion (Reinforced)
- Company A
- Company B
- Company C
- Company D

75 mm Recoilless Gun Platoon

4.2" Mortar Platoon

75 mm Pack Howitzer Battery

Marine Air Group 36 (MAG-36) units

H&MS 36

HMR 362, 363

Marine Air Group 15 (MAG-15) units

VMA 223, 224, 323

VMF(N) 542

Marine Air Support Squadron 3 (MASS-3)

Brigade Helicopter Support Unit (HSU)

For the exercise, all elements were based at Camp Desert Rock, Nevada except MAG-15 (432 personnel), which was based at the Marine Corps Auxiliary Air Station (MCAAS), Mojave, California. Direct participation of MAG-15 consisted of twenty-four F9F aircraft in simulated close air support strikes in the area of troop operations as part of the exercise. The Marine Corps Camp Detachment, which operated the Marine Corps facilities at Camp Desert Rock, consisted of 162 personnel. Of these, 142 participated in the actual Shot BEE exercise (essentially as observers). Thus, total direct participation is estimated at 1843 personnel:

3rd MCPAEB	2271
less MAG-15 personnel	-432
plus 24 F9F pilots from MAG-15	+24
less 20 (162-142) from Camp Det.	-20
Direct Participants	1843

Reference 4 indicates that the planned number of U.S. Marine Corps participants at Shot BEE was 1950.

2.3 CONCEPT OF OPERATIONS

The details of the exercise plan for the 3d MCPAEB are discussed in References 1 and 3. The basic concept of these troop exercises conducted in conjunction with

Shot BEE was to conduct a coordinated air-ground (close air support/helicopter assault) exercise against a set of objectives immediately following, and simulating exploitation of the initial effects of, the employment of a nuclear weapon by friendly forces. However, due to radiological safety considerations, the actual operations would be conducted at distances considerably removed from the actual shot area. Figure 2 indicates the general plan of the exercise. Table 1 indicates the planned composition and activities of the various "serials" into which the brigade was organized for the exercise. The bulk of the exercise troops would observe the shot from Loading Zones 1, 2, and 3 (simulated aircraft carriers), 6 to 12 miles (10 to 19 kilometers) to the south and southwest of GZ. They would then be lifted by helicopters to designated Landing Zones A and B about 7 miles (11 kilometers) to the west of GZ and in the vicinity of tactical objectives NAN and SUGAR. Upon landing, the marines would form up and conduct simulated ground assaults on these objectives. They would be supported by timely close air support strikes by marine aircraft and by direct organic artillery fire. Upon seizure of their initial objectives, a contingent of the troops (2nd Plat, Co A) would make a helicopter airlift/ground assault on Objective WILLIAM nearby. This movement would be accompanied by an air delivery of supplies to the ground troops occupying the newly-seized objective area by four R4Q aircraft from the Marine Corps Air Station (MCAS) at El Toro, California.

A contingent of 568 troops would observe the shot from trenches 3500 yards (3200 meters) southwest of GZ. They would then march south to Loading Zones 4 and 5 and be lifted by helicopters to Landing Zones A and B to join in the assault on objectives NAN and SUGAR.

The various helicopter lifts involved in these maneuvers were designated as Phases X-RAY, YOKE, and ZEBRA, as indicated in Figure 2.

On completion of these exercises, the marine assault troops would be trucked from the exercise area to the vicinity of the Shot BEE display area for a walk-through tour of the displays, viewing the effects of the detonation on the equipment. They would then entruck for the return trip to Camp Desert Rock.

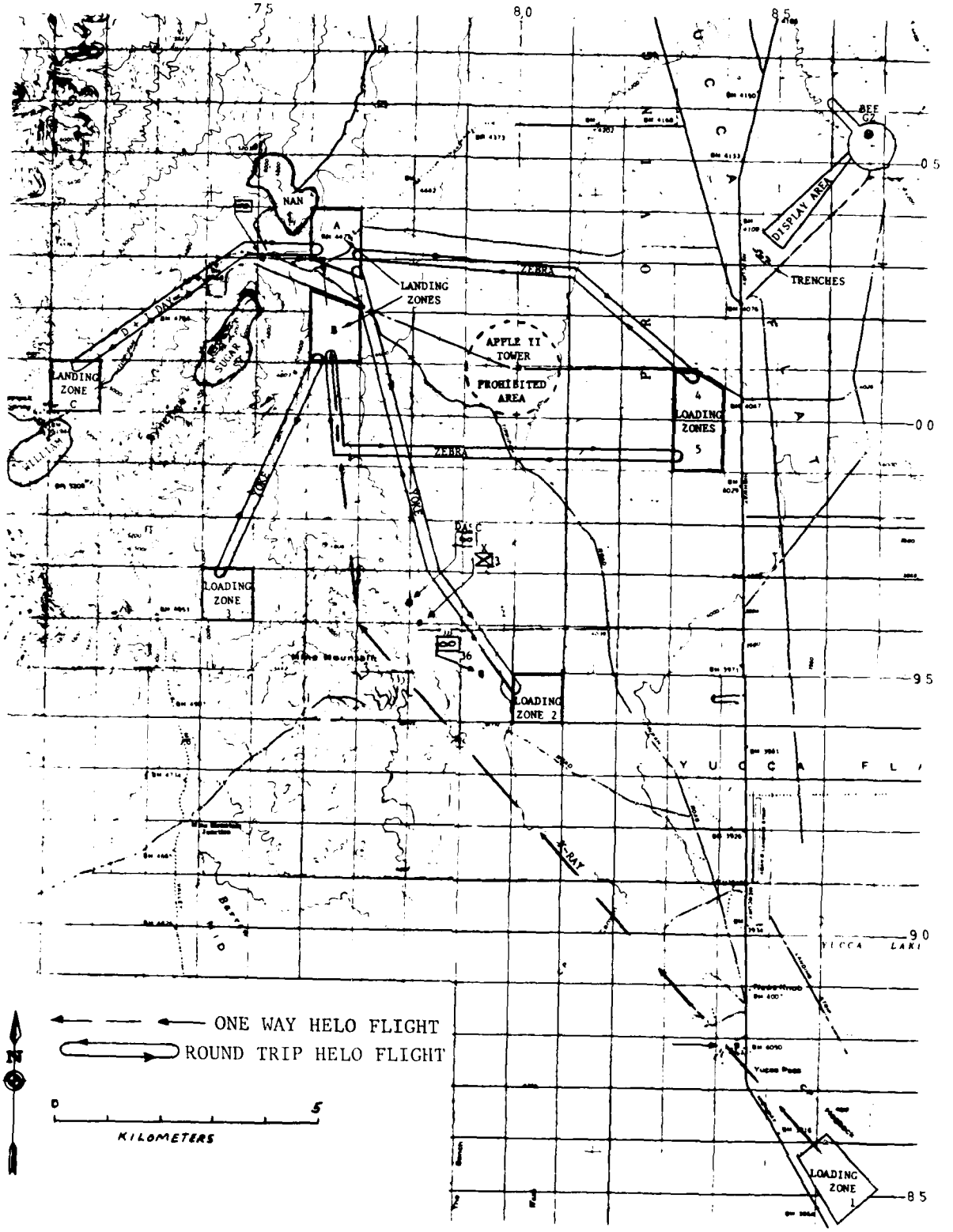

Figure 2. General Plan of the 3d McPAEB Exercise at Shot BEE

Table 1. Planned Troop Activities, 3d MCPAEB, Shot BEE

SERIAL	COMPOSITION	ACTIVITIES	
		PRE-SHOT	POST-SHOT
1.	H&S Co MAG-36 MASS-3	On D-1, occupy Command Posts (simulated ships).	Conduct operation from Command Posts.
2.	Co B, 1st Plat Co C, 1st Plat 2 Radiac Teams HSU MAG-36	On D-1, Proceed to Loading Zone 1; bivouac overnight, witness Shot BEE from this location.	Helicopter lift to Landing Zone A. Commence assault on Objective NAN. Helicopters proceed to loading Zones 2 and 3.
3.	H&S Co Co B (less 1st Plat) HSU MAG-36 Medical Personnel	On D-1, Proceed to Loading Zone 2; bivouac overnight, witness Shot BEE from this location.	Helicopter lift to Landing Zone A. Commence assault on Objective NAN.
4.	H&S Co Co C (less 1st Plat) 75 mm R.G. Plat 4.2" Mortar Plat 75 mm Pack Howitzer Btry HSU MAG-36 Medical Personnel	On D-1, Proceed to Loading Zone 3; bivouac overnight, witness Shot BEE from this location.	Helicopter lift to Landing Zone B. Commence assault on Objective SUGAR.
5.	H&S Co Co A (1st & 2nd Plat) Co D (1st & 2nd Plat) 75 mm Pack Howitzer Btry HSU MAG-36	On D-Day at about H-3 hrs. proceed from Camp Desert Rock to trench area (3500 yards SW of GZ). Witness Shot BEE from trenches.	When directed, leave trenches, march south on Mercury Highway to Loading Zone 4 for helicopter lift to Landing Zone A. Join assault on Objective NAN.

Table 1. (continued)

SERIAL	COMPOSITION	ACTIVITIES	
		PRE-SHOT	POST-SHOT
6.	H&S Co Co A, 3rd Plat Co D, 3rd Plat 75 mm R.G. Plat 4.2" mortar Plat MAG-36	On D-Day at about H-3 hrs, proceed from Camp Desert Rock to trench area (3500 yds SW of GZ). Witness Shot BEE from trenches.	When directed, leave trenches, march south on Mecury Highway to Loading Zone 5 for Helicopter lift to Landing Zone B. Join assault on Objective SUGAR.
-	Observers and Camp Detachment Personnel	On D-Day, arrive at trenches at about H-30 minutes. Witness Shot BEE from trenches.	When released, proceed to display area to tour and observe effects. Return to Camp Desert Rock (See Reference 8).
-	Co A, 2nd Plat	N/A	On D + 1, helicopter lift from Landing Zone A to Landing Zone C for assault on Objective WILLIAM (actually occurred on D-Day, see Section 2-5).
-	All exercise troops	N/A	On D+1, entruck at Landing Zone A to display area to tour and observe effects. On completion, return to Camp Desert Rock (actually occurred on D-Day, See Section 2-5).

2.4 PRESHOT OPERATIONS

The 3d MCPAEB was formed at Camp Pendleton, California. The various units proceeded to Camp Desert Rock by airlift and surface convoys, arriving over the period 25 February (Camp Detachment) to 11 March 1955. These movements were timed to meet an 18 March ready date for Shot BEE. The shot was postponed twice before D-day was confirmed for 22 March.

Training and pre-shot rehearsal exercises, some of which were conducted in the forward area, included the following:

- 12 March. A small number of Brigade personnel, principally officers, observed the detonation of Shot HORNET. Except for those test shots at which observers were designated (in which case the locations and procedures were as indicated in Reference 6), the normal location for observing test shots was at News Nob (about 1. kilometers south of Shot HORNET). Since Reference 4 does not indicate that there were any observers designated for Shot HORNET, it is assumed that they observed the shot from News Nob and that they received no measurable dose of radiation from this activity.

- 15 March. Observers inspected the pre-shot condition of the equipment set up in the display area, three days before the planned shot date of 18 March. There are no indications that any 3d MCPAEB personnel took part in this activity.

- 16 March. A one-hour radiological safety orientation was given to all troops by an officer from the exercise staff.

- 17 March. A rehearsal of the tactical portion of the exercise was conducted in the forward test area. The reference indicates that the rehearsal proved to be valuable in checking out time and space factors as well as wind and dust conditions at the loading and landing zones. The

rehearsal likely included all of the planned helicopter troop lifts from the five loading zones (1 through 5) to the two initial landing zones (A and B) and the subsequent airlift from Landing Zone A to Landing Zone C.

- 19 March A second rehearsal was conducted in the exercise area to verify achievement of the desired degree of air coordination. This rehearsal involved only six close support aircraft, four helicopters, and appropriate communications personnel.

2.5 SHOT SCENARIO

Actual troop movements for Shot BEE began on 21 March (D-1) with the departure of Serials 1 thru 4 from Camp Desert Rock to their planned initial positions (See Table 1) in the exercise area. Although most of this troop movement was accomplished by ground vehicle convoys, some of the troops destined for Loading Zone 1 were airlifted by helicopter. Details of the various troop movements are contained in Reference 3.

Serial 1 personnel departed Camp Desert Rock at approximately 1300 hours on 21 March (D-1) destined for their command post areas near Loading Zone 2 (Figure 2). Serials 2, 3, and 4 departed camp shortly afterwards, and all had arrived at their respective initial positions (Loading Zones 1, 2, and 3, respectively) by 1500 hours on D-1. Thirty helicopters, carrying the remaining troops, departed Camp Desert Rock at approximately 1430 hours on D-1 and flew directly to Loading Zone 1, where they remained for the shot the following morning. All of the troops in Serials 1 through 4 (a total of 931 personnel) were in their positions by 1800 hours on D-1, 21 March. This marked the first time that the Atomic Energy Commission permitted encampment by troops in the forward area on the night preceding a shot.

At 0219 hours on 22 March, Serials 5 and 6 totalling 568 personnel, along with 142 marines from the Camp Detachment, departed Camp Desert Rock by ground vehicles. They arrived at the trench area 3500 yards (3200 meters) southwest of the shot tower (see Figure 2) at about 0330 hours.

The entrenched troops were given an orientation by the Deputy Exercise Director of Desert Rock VI on the sequence of procedures and safety precautions to be observed during the period immediately preceding and following the detonation. Brigade troops elsewhere in the test site were at sufficient distances that they were not required to be in trenches. These troops were instructed to face away from GZ, sit on the ground, and shield their eyes. At approximately three seconds after the detonation they were allowed to stand and face the shot area to observe the rising fireball.

Permission to begin the tactical exercise was granted at 0510 hours, five minutes after the shot. As indicated in Reference 3, the maneuver then proceeded as planned (Table 1 and Figure 2). Exceptions, detailed in the reference, are indicated in the following summary.

Two helicopters, each bearing a two-man radiological monitor team, departed Loading Zone 1 at 0512 hours and arrived at Landing Zones A and B eight minutes later. The main elements of Serial 2 then commenced Phase X-RAY, with the first troop lift departing Loading Zone 1 at 0515 hours (Figure 2). While these troops were enroute to Landing Zones A and B, the monitor teams landed, conducted their surveys, and reported that the two landing zones were radiologically safe. Thus the scheduled troop lift proceeded without delay. It is estimated that Phase X-RAY was completed by 0545 hours (H + 40 min).

The second phase (YOKE-I) commenced immediately after completion of Phase X-RAY. This consisted of helicopter lift of Serial 3 from Loading Zone 2 to Landing Zone A and Serial 4 from Loading Zone 3 to Landing Zone B. This phase was completed at 0630 hours.

While assault phases X-RAY and YOKE-I were in progress, the 568 assault troops of Serials 5 and 6, who had witnessed the detonation from the trenches, were marching down Mercury Highway to Loading Zones 4 and 5, approximately 2 miles (3 kilometers) farther south (Figure 2). They arrived at their respective loading zones and were ready for embarkation by the time assault phase YOKE-I was completed.

Assault phase ZEBRA consisted of airlifting these troops from Loading Zones 4 and 5 to Landing Zones A and B, respectively. It is estimated that phase ZEBRA was completed at approximately 0800 hours.

Upon completion of phase ZEBRA, the helicopters began assault phase YOKE-II. This phase consisted of helicopter movement of the few remaining troops in Serials 3 and 4, plus weapons, equipment and supplies from Loading Zones 2 and 3 to Landing Zones A and B, respectively. With the execution of assault phase YOKE-II, the entire airlift plan was completed at 0900 hours. All assault elements (approximately 1100 personnel) and equipment had been lifted to Landing Zones A or B and the rifle companies had begun maneuvering towards their objectives. The helicopter lifts had been completed more than an hour earlier than the estimated time. Reference 3 indicates that this was primarily due to the almost total availability of the helicopters. Planned times had been based on an estimated helicopter availability of 80 percent.

When the shot date was set, the troop maneuver had been planned for approximately 30-36 hours, with troops to depart the exercise area at 1430 hours on D+1, 23 March. However, during the execution of the D-day landing plan, it was learned that another shot (ESS) had been tentatively scheduled for 23 March. It therefore appeared that the troops might not be permitted to remain in the exercise area during the night of 22-23 March and conduct the scheduled events on 23 March. It was decided to take advantage of the additional time made available by the accelerated execution of the landing plan and execute all of the exercise events during the remaining morning and afternoon hours of 22 March.

At 0955 hours, while most of the assault troops were moving to seize Objectives NAN and SUGAR, helicopter assault phase WILLIAM (originally scheduled for D+1) was executed. This consisted of movement of one reinforced rifle platoon (2nd Plat, Co A) by helicopter from Landing Zone A to Landing Zone C (Figure 2). Upon reaching the landing zone, the assault platoon moved out to seize Objective WILLIAM. Meanwhile, the R4Q aircraft that were scheduled to make the air drop of simulated supplies in support of the assault on Objective WILLIAM on D+1 had been contacted at MCAS El Toro. Arrangements were made to conduct the resupply mission as early as possible.

The four aircraft arrived at 1330 hours and completed the air drop at 1358 hours. With the air drop executed and all objectives seized, the exercise was terminated at 1500 hours on D-day.

Upon completion of the exercise, all maneuver troops (Serials 2-6) reported to a predesignated assembly area at Landing Zone A, where vehicle convoys then transported them to the equipment/material display area, about six miles (9.6 kilometers) to the east. Personnel from the command post area (Serial 1) departed at the same time and were transported directly to the display area. Reference 3 indicates that the time of arrival at the display area for all personnel was approximately 1530 hours and that the troops spent approximately two hours viewing the damaged equipment. They then re-boarded their vehicles and departed for the trip back to Camp Desert Rock, where they all arrived by 2000 hours, 22 March. Troop movements in the display area are reconstructed in Section 4 in the development of estimates of troop exposure to residual radiation.

2.6 POST-SHOT ACTIVITIES

As indicated in Reference 4, on 23 March, 1955, six officers and three (possibly four) enlisted men (none identified) from the 3rd MCPAEB observed the detonation of Shot ESS, an underground burst in Area 10 (coordinates 849138). The observer position for this shot was in the open in Area 2 (coordinates 773104) near the TURK ground zero, 9000 yards (8200 meters) from the shot. This activity resulted in a small exposure to the residual radiation from Shot TURK, detonated 16 days before. The resultant dose is calculated in Reference 6. After the shot at 1230 hours, the observers returned to Camp Desert Rock.

Brigade elements began departing Camp Desert Rock on 23 March. The main elements of the brigade arrived at their home bases in California on 25 March, with the Camp Detachment returning on 31 March.

Section 3
INITIAL RADIATION

As indicated in Section 2, Serials 5 and 6 (568 personnel) and 142 personnel from the Camp Detachment were positioned (along with the 525 observers) in the trenches located 3500 yards (3200 meters) to the southwest of GZ when Shot BEE was detonated. All other 3d MCPAEB participants in the Shot BEE exercise were positioned at distances of at least seven miles (11 kilometers) from GZ and were well beyond the range of measurable initial radiation. Because the 710 marines in the trenches were colocated with the observers, they were exposed to the same initial radiation levels and received appproximately the same radiation dose as the observers. Reference 6 provides the calculation of initial radiation dose for the observers in trenches at Shot BEE. This discussion is limited to brief highlights from the reference.

3.1 COMPUTATIONAL METHOD

Because the troops were located in trenches at the time of detonation, the calculation of the initial radiation dose is accomplished in two steps. First, the free-field radiation environment above the trenches is determined. This environment is then used to calculate the radiation doses to personnel in the trenches.

In the first step, the neutron and gamma radiation environment is determined from radiation transport codes ATR4 (Reference 7) and ATR4.1 (Reference 8). The neutron and neutron-induced gamma radiation are sensitive to the hydrogen (water) content of the soil (Reference 9). Hence, ATR 4, which contains provisions to apply appropriate local soil corrections for this factor, is used for these calculations. Neither fission product gamma nor prompt* gamma radiation are sensitive to hydrogen in the soil. Therefore, ATR 4.1, which uses a West German soil type but contains improved source-energy dependent ground correction factors, is used for the gamma calculations.

A required input to the ATR codes is the weapon neutron output spectrum, which is estimated by the method described in Reference 8. This spectrum is used in ATR4 to

*Defined as from the fission reaction.

calculate the neutron dose as a function of range. Figure 3 shows the results of the neutron dose calculations.

The calculated gamma dose agrees well with the measured dose in the range 1000-2000 yards. However, the measured gamma data for Shot BEE display a rather abrupt change in slope at approximately 2000 yards, as shown in Figure 4. The ATR calculations are unable to duplicate this behavior. Because the ATR gamma doses are consistently lower than the measured doses at ranges beyond this change in slope, a high-sided estimate of dose at the trench location is obtained by extrapolation from measured data. Individual gamma dose components (prompt, secondary, and debris gamma) are then estimated by increasing the ATR-predicted component doses proportionally to agree with the extrapolated total dose.

The second step of the calculation uses the free-field radiation environment to determine the dose within the trench. It is convenient to define a trench factor as the ratio of dose (neutron or gamma) in the trench to dose (neutron or gamma) above the trench. These factors must be calculated for each of the major components of radiation--neutron, secondary gamma (created by neutron capture or inelastic scattering in the atmosphere and ground), local gamma (created locally by neutron capture in the trench walls), and fission product (debris) gamma. It is found that the trench factors depend also on ground range, height of burst, weapon yield, trench dimensions, and depth in the trench. For Shot BEE, the troops were in trenches approximately two feet wide and five feet deep. The in-trench free-field neutron and gamma doses are calculated at a depth of 2.33 feet below the lip of the trench, which corresponds approximately to the mid-torso depth for personnel in a crouched position. For personnel standing upright in the trench, as probably occurred soon after passage of the shock wave, free-field doses are calculated at a point 0.5 feet below the lip at the mid-trench position; this corresponds approximately to the location of chest-worn film badges for standing personnel.

The in-trench dose (in rads) is converted to an equivalent tissue dose (in rem) using the quality factors and methods prescribed in Reference 12. It is found that the "effective" quality factor for this rad-to-rem conversion for neutrons is 13 for the ranges of interest. The quality factor for gamma radiation is taken to be unity. The factors that are used to convert the in-trench free-field doses to film badge

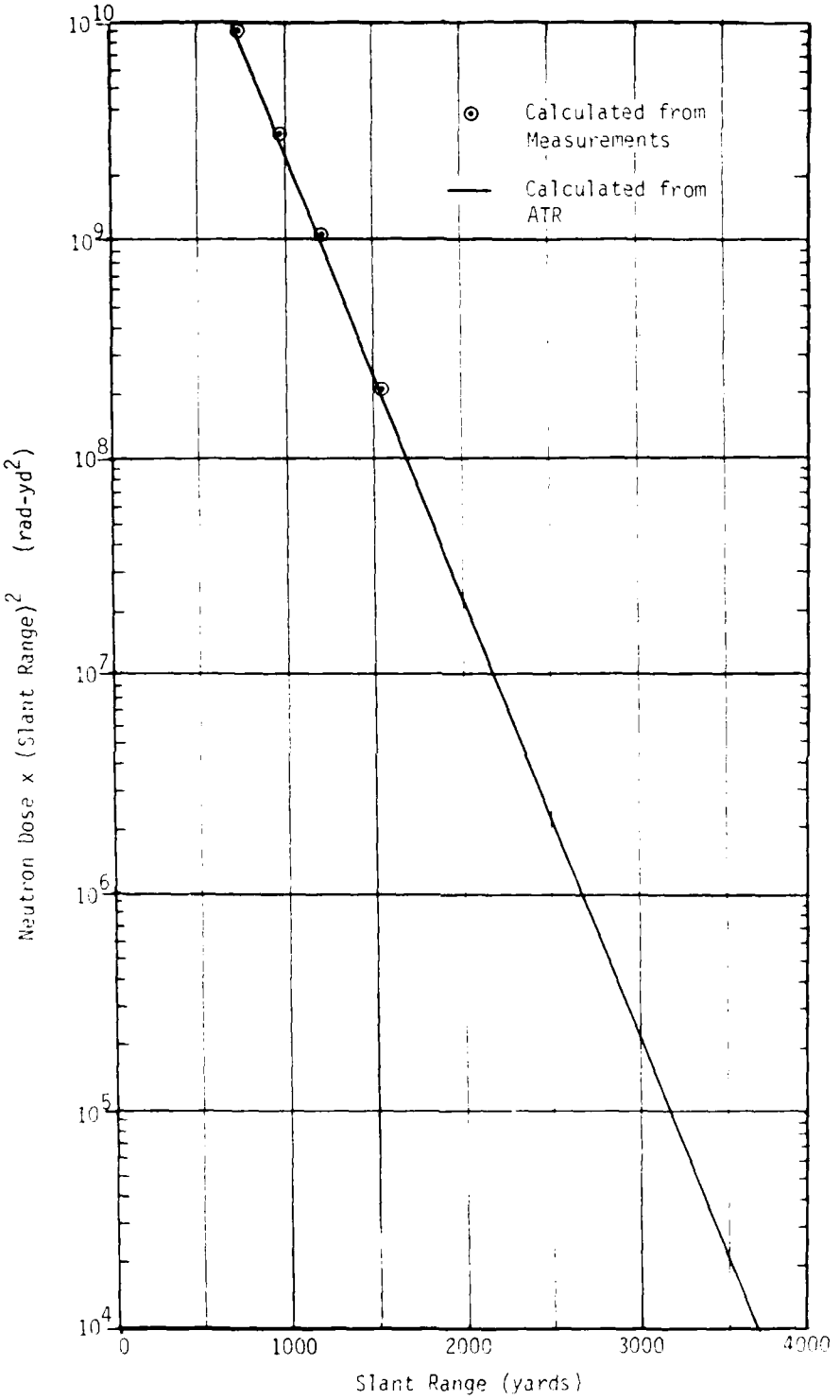

Figure 3. Shot BEE Neutron Dose

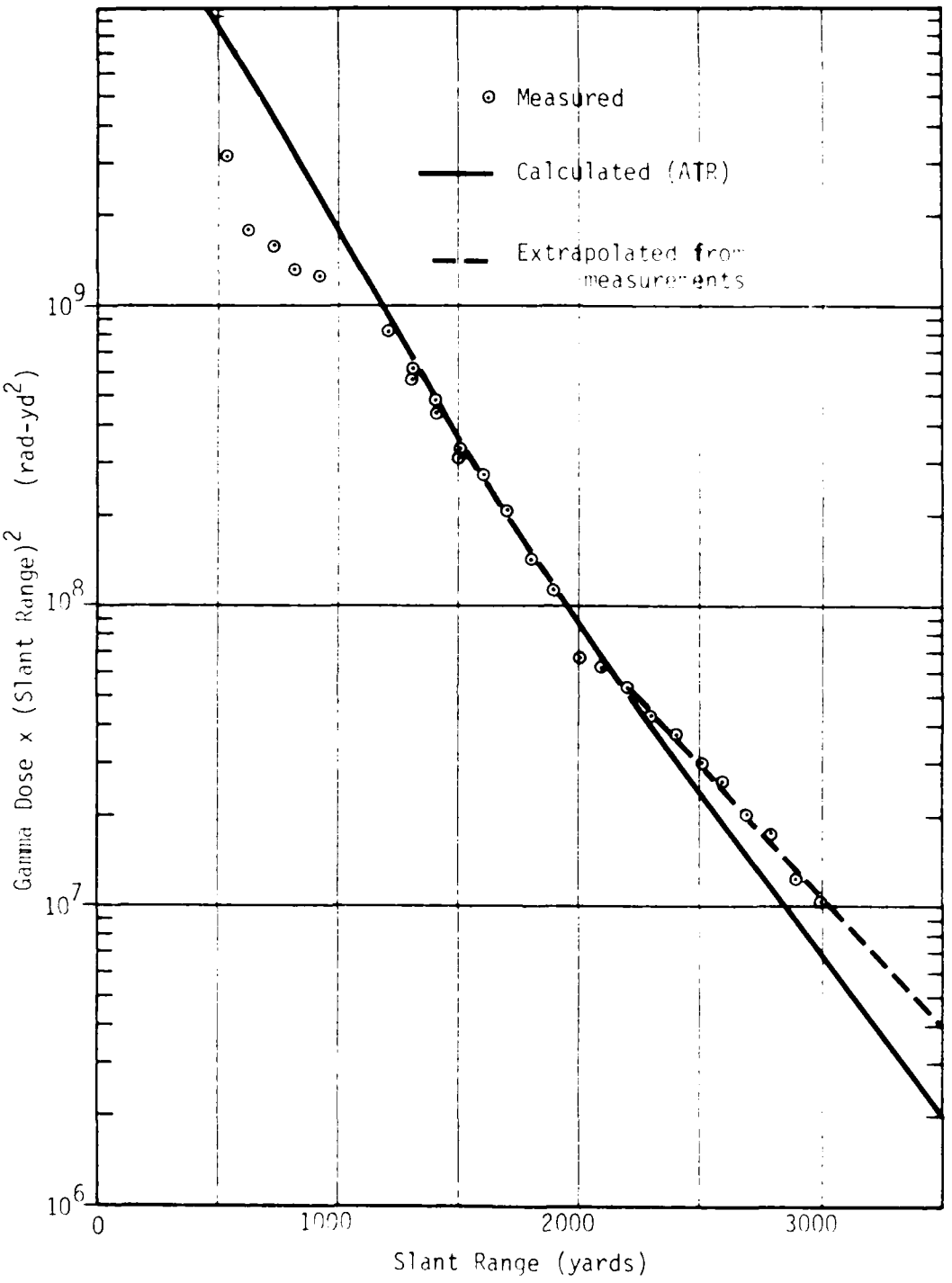

Figure 4. Shot BEE Initial Gamma Dose

(chestworn) readings were developed from calculations utilizing the adjoint mode of the computer code MORSE (Reference 11). These film badge conversion factors are strongly dependent on the posture and orientation of the personnel in the trench; mean values of these parameters were determined from MORSE calculations involving extreme variations in individual posture and orientation. The "dose equivalent in trench" values reported for Shot BEE in Reference 6 are the equivalent tissue dose for neutron radiation and the film badge dose for gamma radiation.

3.2 RESULTS

As indicated in Reference 6, neutron fluence measurements for Shot BEE were taken from References 12 and 13, corrected by the factors in Reference 14, and converted to dose. The ATR fit to these doses is displayed in Figure 3. The measured gamma doses (from Reference 15), the ATR gamma dose curve, and the extrapolation from measured data are shown in Figure 4. The gamma dose obtained by extrapolation is 95 percent higher than the ATR-calculated dose at the trench location (3500 yards from ground zero). This higher value is used as the dose estimate.

The results of the dose calculations of initial radiation at the trench location are summarized from Reference 6 as follows:

	Prompt Gamma	Secondary Gamma	Debris Gamma	Local Gamma	TOTAL GAMMA	NEUTRON
Tissue Dose above Trench (mrad)	10	235	85	-	330	3
Trench Factor	.03	.015	.19	.08**	-	.25
Film badge Conversion Factor	.46	.53	-	.7	-	-
Dose Equivalent in Trench (mrem)	<1*	2*	16*	<1*	18*	10

*Film Badge Dose.
**Applied to neutron dose above trench.

Section 4
RESIDUAL RADIATION

Residual gamma doses are reconstructed for each of the elements of the brigade. Detailed time/position information is combined with the residual radiation field constructed by a computerized methodology described in Reference 6. This methodology combines gamma intensity data from all radiation surveys after the shot to construct the gamma environment within confidence limits. Doses can then be determined for any specified time/position scenario.

Film badge dose estimates must reflect the presence of the human body in the measured radiological environment. Despite the penetrating ability of gamma rays from fission and activation products, the body affords some shielding; hence, the gamma dose to any organ depends on the geometry of the radiation source and the body position. In order to represent reconstructed film badge readings, gamma doses are calculated for the surface of the chest, where a film badge is normally worn. The calculated film badge dose is derived from the integrated free-field gamma intensity through the conversion factor 1 R $\longrightarrow$ 0.7 rem as used in previous reports (e.g., Reference 6).

Because of the limited data concerning the specific details of troop activities, estimates are required for rates of movements and the stay times at various display lines. Rates of movement are as described in or inferred from the operation plan (Reference 1), allowing for inertial aspects of large groups. For example, it is assumed that in the post-shot tour of the equipment display, a reasonable set of parameters (consistent with the reported times and the necessity to complete the walk-through before dark) is 70 yds/min walking speed and 5 minutes stay time at each equipment display grouping encountered. Additional assumptions are noted as required.

4.1 RADIOLOGICAL SAFETY AND RADIATION MEASUREMENTS

The 3d Marine Corps Provisional Atomic Exercise Brigade operated under the standard radiological safety, monitoring, and decontamination procedures established for Desert Rock VI participants except that brigade personnel had a major role in rad

safe activities. As indicated in Reference 1, this included issue and control of film badges, the provision of monitor teams for the exercise area activities, and decontamination of troops, vehicles, and equipment. Specifics included:

- The maximum permissible dose established for Marine Corps personnel at Exercise Desert Rock VI would be 6 rem, of which no more than 3 rem could be initial radiation. While there is no specific statement of maximum intensities of radiation levels, it is assumed that the 5 R/hr limit for observers specified in Reference 4 also applied to the exercise troops.

- Two monitoring teams from the 1st Battalion would be embarked in helicopters that would precede by three minutes the initial lift of troops from Loading Zone 1. They would accomplish the initial monitoring at Landing Zones A and B before arrival of the initial troop lifts.

- An emergency monitor team would be located in Loading Zone 2. This team would accomplish the initial monitoring in the event that the two assigned monitor teams failed to reach Landing Zones A and B. In this event, all other airborne helicopters would orbit until this team could be lifted to accomplish the monitoring mission before the initial wave of assault troops would be landed.

- Monitoring teams would accompany the assault force to Objectives NAN, SUGAR, and WILLIAM and, upon seizure of those objectives, conduct a complete area survey, reporting results to the brigade headquarters.

Desert Rock rad-safe personnel provided their usual service of surveying the area of operations. This included provision of six mobile teams from Camp Desert Rock to conduct the necessary monitoring survey in the trench and display area and control of the movement of personnel through the display area. There is no indication of the specific film badge issuance policy. However as Section 6 of this report indicates, badges were issued to at least 25 percent of the brigade personnel.

4.2 EXPOSURE TO RESIDUAL GAMMA RADIATION

The pre-shot and post-shot activities of the 3d MCPAEB in Exercise Desert Rock VI involved exposure to two residual radiation fields as follows:

1. The rehearsal on 17 March and the post-shot maneuvers on 22 March, which were conducted in an area in the downwind vicinity of Shot TURK (43 kilotons detonated on 7 March).

2. The inspection of the equipment displays located 500 to 2800 yards southwest of the Shot BEE GZ involving exposure to the residual radiation field of Shot BEE.

For the purpose of assessing exposure to residual radiation there are two principal subgroups of the Marine Brigade; Serials 1 through 6 and the 142 personnel from the Camp Detachment. As Reference 3 indicates, the Camp Detachment personnel duplicated the pre- and post-shot activities of the observers and were not otherwise involved in the exercise. Their residual radiation dose is the 0.83 rem calculated for the observers in Reference 6.

The residual radiation doses of the maneuver personnel (Serials 1 through 6) resulted from three exposures as follows:

17 March rehearsal (residual radiation from Shot TURK)
22 March exercises (residual radiation from Shot TURK)
22 March post-shot tour of displays (residual radiation from Shot BEE).

Figure 5 shows the computer reconstruction of the residual radiation field from Shot TURK at H+1 hour on 7 March. The dashed extensions of the radiation contours are derived from several initial survey readings from Reference 5 normalized to the H+1 hour readings as indicated in the figure. The bulk of the rehearsal and exercise activities took place in areas of residual radiation activities which at H+1, were between 10 and 100 mr/hr. Applying the standard $t^{-1.2}$ decay rate to 100 mr/hr results in an estimated intensity at the time of the rehearsal of 0.14 mr/hr. Reference 3 does not provide specific times of the rehearsal, but indicates that it was a full scale

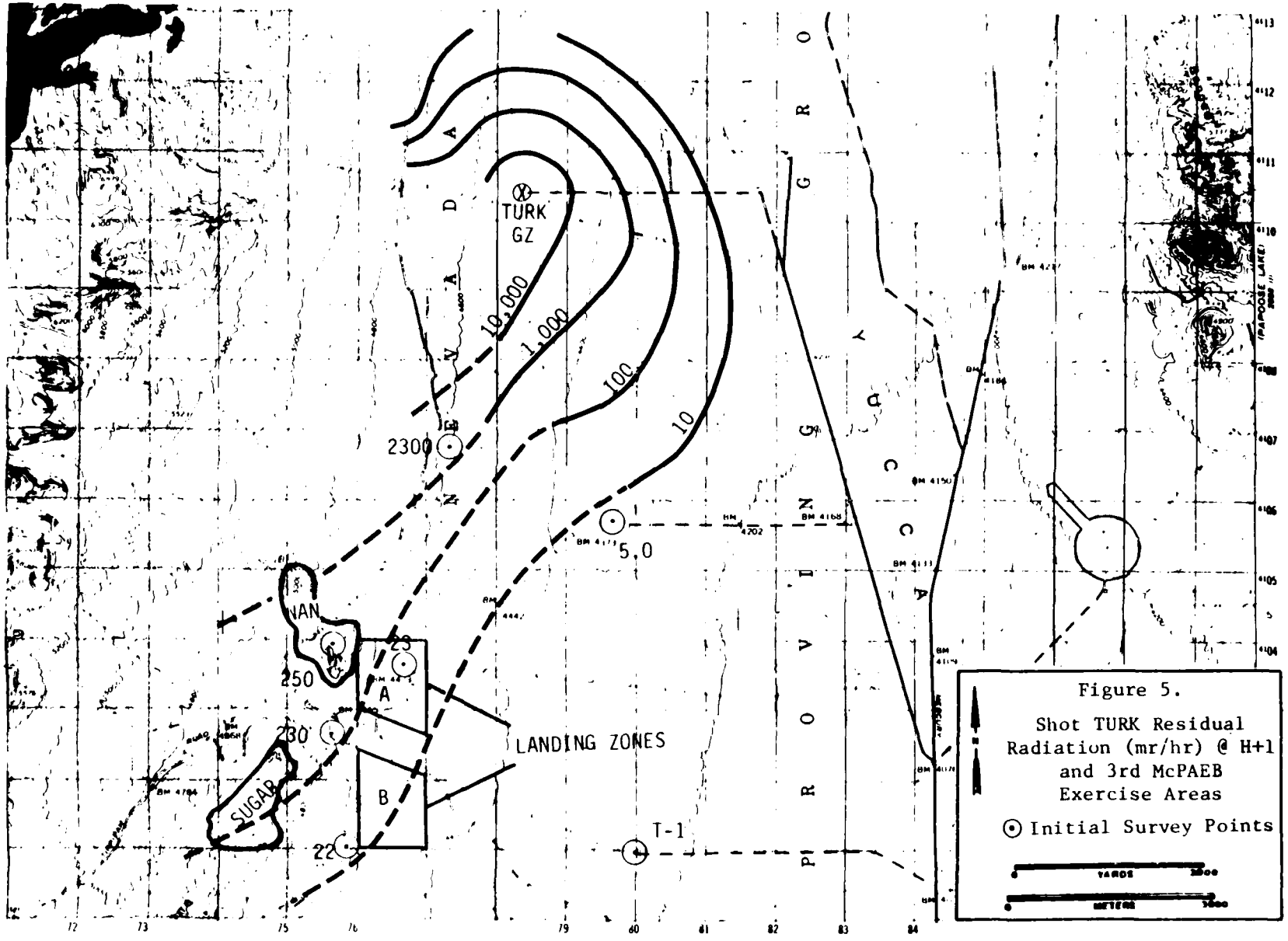

Figure 5.

Shot TURK Residual Radiation (mr/hr) @ H+1 and 3rd McPAEB Exercise Areas

⊙ Initial Survey Points

rehearsal. It is therefore estimated that the marines were in the area for a period of about five hours. This results in an exposure of 0.07 mr and a film badge dose (1R⟶ 0.7 rem) of 0.5 mrem for the rehearsal.

Reference 3 indicates that on 22 March, troops began to arrive at Landing Zones A and B and commenced maneuvers at about 0630. All maneuver troops arrived in the area by 0900. Upon termination of the exercise at 1500, all of these troops entrucked and departed for their tour of the display area of Shot BEE, thus, they were in this area for 6 to 8½ hours. By this time the intensity of the residual radiation from Shot TURK over most of the exercise areas had decayed to a level of 0.09 mr/hr. Thus the exercising troops were exposed to 0.75 mr which would result in a film badge dose of about 0.5 mrem. Therefore, the residual radiation doses from Shot TURK at both the rehearsal on 17 March and the exercises on 22 March are negligible.

The third and most significant exposure to residual radiation of the 3d MCPAEB troops occurred during their inspection tour of the Shot BEE equipment display area. The dashed curves (from Reference 5) in Figure 6 indicate the contours of residual radiation from the shot at H+1. The dotted loop through the display area indicates the estimated walk-through route of the troops. The numbers 1 through 5 indicate the various display line positions.

The maneuver was terminated at 1500 hours (Reference 3), and the troops were then assembled, entrucked and moved to the vicinity of the trenches. From this point they toured the display area on foot to observe the effects of the shot on the various displays. This dose reconstruction is based on an estimate that this was completed at about 1750 hours, at which time the troops reembarked aboard the vehicles for their return, all arriving at Camp Desert Rock by 2000 hours on 22 March. The completion of the maneuvers at 1500 followed by assembly, entrucking, vehicle travel of approximately 6 miles, detrucking and completing their walking tour of the display area by about 1750 hours implies a somewhat shorter time devoted to the tour than the two hours of the earlier tour by the observers (Reference 6) and Camp Detachment personnel. Conversely, completion of the tour, entrucking and returning to Camp Desert Rock at 2000 may imply a somewhat slower than usual return trip to camp. There are, however, indications of a strong motivation to complete at least the walking tour before darkness (acceleration of the schedule as indicated in Section 2.5).

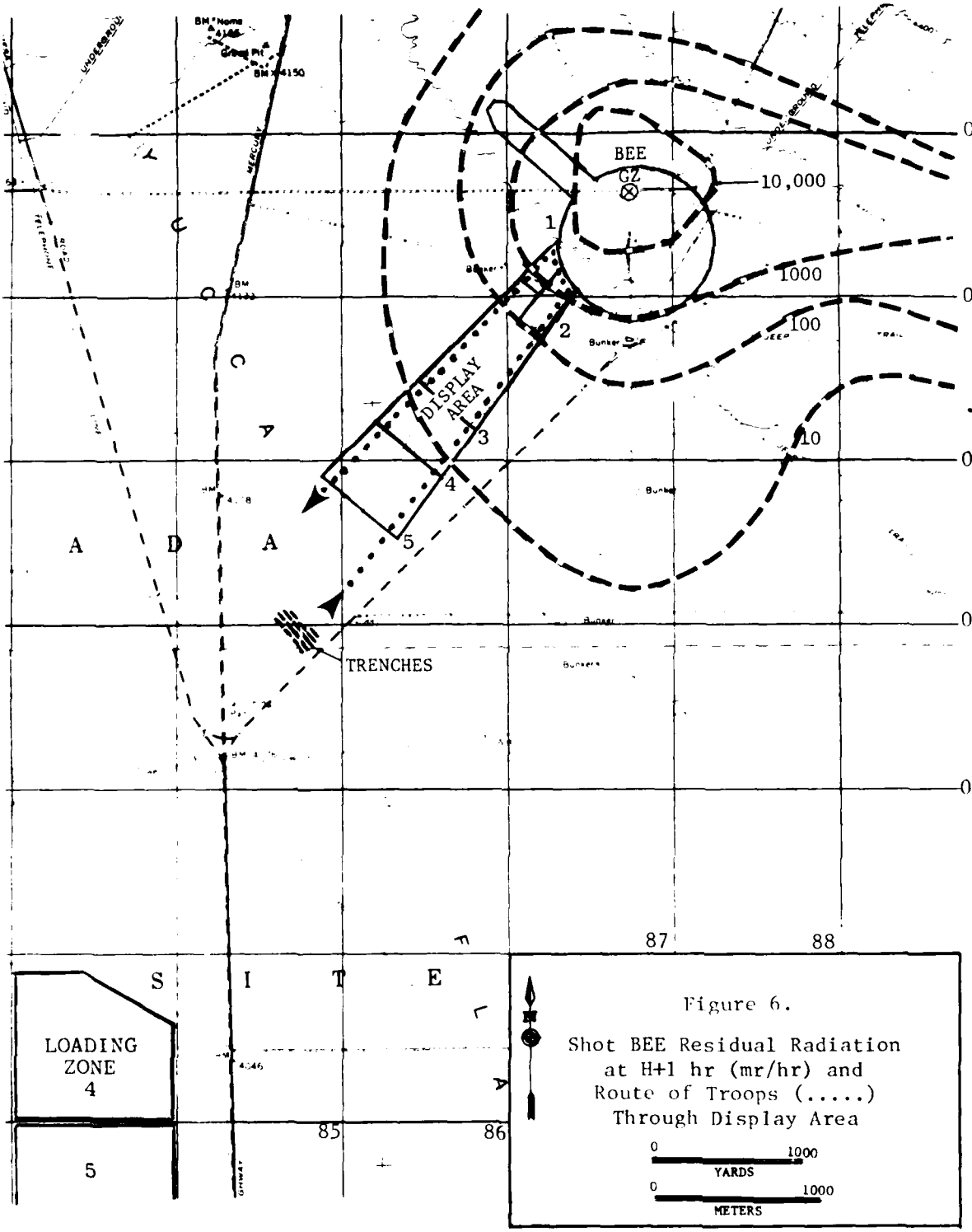

Figure 6.

Shot BEE Residual Radiation at H+1 hr (mr/hr) and Route of Troops (.....) Through Display Area

By considering the above, the itinerary of the inspection of the display by the marines is reconstructed as follows:

- The marines detrucked, formed up and began their tour from a position in the open area in front of the trenches (about 3200 yards--2900 meters--southwest of GZ) by 1600 hours.

- They toured at a walking speed of 70 yards per minute (2.4 mph), followed the route indicated in Figure 6, stayed about 5 minutes at each of a total of 7 display positions (positions 1 and 2 each had two display lines), and remained outside of the hardtop area while viewing the displays in Positions 1 and 2.

- They completed their tour, having walked more than 5000 yards, as they passed the Position 5 displays (2800 yards southwest of GZ) at about 1750 hours.

The above itinerary permits the troops to view all of the displays since the maximum intensity encountered is calculated to have been 3.86 R/hr at Position 1, about 525 yards from GZ, below the 5 R/hr intensity limit specified for troops in the Desert Rock VI exercises. The calculated film badge dose is 540 mrem.

Table 2 summarizes the calculated residual radiation doses for the two subgroups of the Marine Brigade. The table does not include the unidentified personnel (6 officers and 3 or 4 enlisted men) who observed Shot ESS (see Section 2.6). The dose for this activity was calculated in Reference 6 as 43 mrem.

Table 2. Calculated Residual Radiation Doses for the 3d MCPAEB

	Maneuver Troops (Serials 1 through 6)	Camp Detachment Group (142 personnel)
17 March Rehearsal Residual radiation from TURK	<1.0	-
22 March Exercise Residual radiation from TURK	<1.0	-
22 March (H+0.5 to H+2.5 hrs) Residual radiation in display area (Shot BEE)	-	830
22 March (H+11 to H+13 hrs) Residual radiation in display area (Shot BEE)	540	-
TOTALS	540 mrem	830 mrem

Section 5
UNCERTAINTY ANALYSIS AND TOTAL DOSE DETERMINATION

The sources of error in the calculation of initial and residual radiation doses are examined in order to estimate the uncertainty in the total dose for each of the major groupings of the brigade. As indicated in Sections 3 and 4, the initial radiation doses received by the 710 marines who were in the trenches at shot time were very small compared to the residual radiation doses that they and the bulk of the brigade received as a result of the post-shot walk through of the Shot BEE display area. Reference 6 provides a detailed uncertainty analysis for the troop observers at Shot BEE. As Section 3 of this report indicates, the 710 brigade troops received the same initial radiation dose. The uncertainties in their initial radiation dose are also the same. Accordingly the analysis of uncertainties in initial radiation dose is limited to brief highlights from Reference 6. Emphasis is on the uncertainties in the residual radiation doses received by the personnel of the 3d MCPAEB. All error factors are expressed in terms of 90-percent confidence limits.

5.1 UNCERTAINTIES IN INITIAL RADIATION DOSE

5.1.1 Neutron Dose

The sources of error in the calculation of neutron dose include: (1) uncertainties in doses derived from foil measurements, (2) uncertainties in neutron output spectra of the nuclear device, (3) errors associated with the use of the ATR4 code to extrapolate beyond the range of measured data, and (4) errors in relating above-trench dose to in-trench dose equivalent. Details of the derivation of each of these error factors are in Reference 6. For Shot BEE the neutron dose error factors are as follows:

Source of uncertainty	Error factor
Foil measurements	1.25
Spectral uncertainty	1.15
ATR4 extrapolation	1.15
Above-trench to in-trench	1.25

The distribution of neutron dose levels is log normal so the combined error factor for the neutron dose from Shot BEE is calculated by summing the squares of the logs of the component error factors and then computing the antilog of the square root of the sum. The resultant combined error factor is 1.45.

5.1.2 Initial Gamma Dose

Sources of error in the calculation of initial gamma dose include: (1) uncertainty in experimental film badge readings, (2) extrapolation/interpolation techniques to determine dose at the trench location, (3) errors in relating above-trench dose to in-trench dose, (4) uncertainty in converting in-trench dose to film badge reading for personnel in a fixed position, and (5) uncertainty in personnel reorientation (i.e., standing up) in the trench. While the other sources of error are systematic, the latter two uncertainties provide an indication of the spread in film badge readings expected due to the various orientational factors. Again, details of the derivation of these error factors are in Reference 6. For Shot BEE the initial gamma dose error factors are as follows:

Source of uncertainty	Error Factor
Experimental data	1.4
Extrapolation/interpolation	1.5
Trench factor	1.2
Trench posture	1.5
Standup Time	1.2

The combined error factor for the initial gamma dose from Shot BEE, calculated in the same manner as the neutron dose, is 2.1.

5.2 UNCERTAINTIES IN RESIDUAL RADIATION DOSE

The uncertainty in calculated residual radiation doses arise from two basic sources: (1) gamma radiation environment, and (2) the space-time scenarios of troop movements. The 90-percent confidence limits in the gamma intensity, including the

uncertainty in the decay parameter, are provided by the automated procedure described in Reference 6. Parametric studies using the automated procedure are made to determine the influence of scenario variations on personnel dose. As indicated in Section 4, there are four exposures to residual radiation to be considered:

Event	Group
17 May - Rehearsal (Residual radiation from Shot TURK)	Serials 1 through 6
22 May - Post-shot maneuvers (Residual radiation from Shot TURK)	Serials 1 through 6
22 May (H+0.5 to H+2.5 hrs) Walk-through in company with observers (Residual radiation from Shot BEE)	142 personnel from Camp Detachment
22 May (H+11 to H+13 hrs) Walk-through of display area (Residual radiation from Shot BEE)	Serials 1 through 6

As indicated in Section 4.2, the doses received from exposure to the Shot TURK residual radiation field were negligible. The following discussion develops the uncertainties associated with the exposure of the Camp Detachment personnel to residual radiation from Shot BEE and the later exposure of Serials 1 through 6 to residual radiation from Shot BEE.

5.2.1 Camp Detachment Personnel at Shot BEE

These personnel accompanied the observers on their post-shot walk-through of the display area. Therefore their exposures to residual radiation and the uncertainties in exposure levels are the same as those calculated for the observers in Reference 6.

Because the innermost display stretched from 500 to 700 yards from GZ, the 142 Camp Detachment personnel would have been able to view some equipment at the 5 R/hr line for all intensity fields within the confidence limits. The only influence of the uncertainty in intensity is with regard to the walking time required to reach the 5 R/hr line. This could have varied ±3 minutes, and probably would have been reflected in the

time spent at the 5 R/hr line. With regard to time alone, a ±5 minutes perturbation to the starting time of the walk-through is assumed. Thus, the confidence limits on intensity imply a dose of 830±180 mrem; those on time imply 830±300 mrem. The overall 90-percent confidence limits are approximately 830±350 mrem.

5.2.2 Residual Radiation from Shot BEE

The post-shot inspection of the display area for Shot BEE by the bulk of the 3d MCPAEB personnel (Serials 1 through 6) took place during a period about 11 to 13 hours after the shot. As indicated in Section 4, the calculated film badge dose which they received from this activity is 540 mrem. There are two types of uncertainty in the calculation; the uncertainty in intensity of the residual radiation encountered and the uncertainty in the estimated time of exposure.

There are three forms of variation in regards to the estimated times of exposure. The time of starting the walk-through of the display area is estimated to be 1600 hours. This could vary by as much as ±15 minutes within the overall time bounds of completion of the exercises at 1500 and completing the walk through in daylight hours. In this time period the decay rate of the residual radiation in the display area was quite small and over this half hour of time spread the difference in film badge dose is calculated to be ± 16 mrem.

A more significant contribution to uncertainties is the actual times spent at each of the display lines. At the time of the walk-through radiation intensities exceeding 10 mr/hr existed only at the two closest positions (1 and 2) within 1100 yards of GZ. The estimate of 5 minute stay times at display positions is uncertain to within a factor of 2, that is $^{+5}_{-2.5}$ minutes. This would result in 90 percent confidence bounds of $^{+299}_{-150}$ mrem.

A third variation in exposure times results from uncertainties in the walking speed of 70 yds/min through the display area, assumed in Section 4 to be motivated by the necessity to complete the walk-through before dark. It is unlikely that this large group (about 1700 marines) would have maintained a higher walking speed, but a

somewhat slower tour at 60 yds/min is not unreasonable. The result of this reduced speed would be to add about 13 minutes to the total walking time in the display area and thereby to add a one-sided upper confidence bound of +43 mrem to the residual radiation dose.

In summary the uncertainties due to times are:

starting times, $\pm$ 15 minutes,	$\pm$ 16 mrem
stay times, $^{+5}_{-2.5}$ minutes,	$^{+299}_{-150}$ mrem
walking speed, 70-60 yds/min	+43 mrem

The combined uncertainties due to times imply a dose of $540\ ^{+302}_{-150}$ mrem.

The uncertainties due to gamma intensity are provided by the computerized reconstruction of the walk-through. This reconstruction indicates that the maximum intensity encountered was 3.86 R/hr with an error factor of about 1.5 in this close-in area. The upper bound on the intensity is truncated to the maximum permissible rate of 5 R/hr (Section 4.1). If such intensities were encountered before reaching the displays closest to GZ this would have precluded close viewing of these displays. The small perturbations in the actual itinerary which might have resulted are not considered. This results in uncertainties in the implied dose due to the 90 percent confidence bounds on intensity of 540^{+230}_{-180} mrem.

Combining the uncertainties due to intensities with those due to times for the walk-through produces overall confidence limits around a best estimate of approximately $540\ ^{+380}_{-235}$ mrem. Since this distribution is approximately log normal the calculated mean film badge dose is slightly higher with confidence limits of $570\ ^{+350}_{-265}$ mrem.

5.3 TOTAL MEAN DOSE SUMMARY

The reconstructed neutron and gamma doses for the various elements of the 3d MCPAEB at Shot BEE are presented in Table 3. From the best-estimate doses of

Sections 3 and 4, and the error distribution of this section, the mean neutron and gamma doses for each of the three groups of marines are calculated. These are presented in the table with estimated 90-percent confidence limits. The neutron dose would not have been recorded by film badges and is not combined with the gamma doses. The total gamma dose is the mean reconstructed film badge dose.

Table 3. Dose Summary for the 3d MCPAEB

Principle Exercise Element	Neutron Dose (rem)	Initial Gamma Dose (rem)	Residual Gamma Dose (rem)	Total Gamma Dose (rem)*
Serials 1 through 4	0	0	$0.57^{+0.35}_{-0.27}$	$0.57^{+0.35}_{-0.27}$
Serials 5 through 6	$0.010^{+0.005}_{-0.003}$	$0.020^{+0.018}_{-0.011}$	$0.57^{+0.35}_{-0.27}$	$0.59^{+0.35}_{-0.27}$
142 Personnel from Camp Detachment	$0.010^{+0.005}_{-0.003}$	$0.020^{+0.018}_{-0.011}$	0.83 ± 0.35	0.85 ± 0.35

*Reconstructed mean film badge dose, neutron dose not included

Section 6
DOSIMETRY

A listing of 2258 U.S. Marine Corps participants in Exercise Desert Rock VI (Operation Teapot), obtained from Headquarters, USMC, identifies 2116 personnel as members of the various specific units of the 3d MCPAEB (24 others are unidentified). This permits comparison with the table of brigade composition in Section 2.2 as follows:

	Section 2.2		USMC List
3d MCPAEB	2271		2116
Less MAG-15 personnel (at MCAAS, Mojave, CA) plus 24 F9F pilots from MAG-15	-432	Less all MAG-15 personnel listed	-317
	+24	Plus 23 MAG-15 personnel listed with film badge readings	+23
less Camp Det. personnel	-20		
Direct Participation	1843		1822

The listing is therefore an essentially complete record of 1822 of the 1843 members of the 3d MCPAEB who were active participants in the Marine brigade exercise at Shot BEE. There are 460 of these personnel for whom film badge readings are indicated. Since they are listed by specific unit assignments, this 25% sample provides a sufficient basis for the detailed and separate breakdowns shown in Table 4 for the rifle companies (Co A through D) and for the other units of the brigade.

As the table shows, this subdivision indicates a much narrower spread of readings for the rifle companies then that of the other units. This is reasonable because the activities of very few, if any, members of a rifle company would vary significantly from those of the company as a whole. In fact, 214 of the 218 badge records for the rifle companies (excluding three readings of zero and one of 690 mrem) are all between 300 and 500 mrem. As indicated in the table, this results in a mean reading of 414 mrem for these personnel.

Table 4. Summary of Dosimetry Records of the 3d MCPAEB

Rifle Companies

UNIT	# PERSONNEL LISTED	# WITH BADGE READINGS	AVERAGE DOSE (mrem)
Co. A	176	67	409
Co. B	170	71	423
Co. C	176	0	--
Co. D	178	80	405
Totals	700	218	

Mean Film Badge Reading of Rifle Companies 410 mrem

Mean Film Badge Reading of 214 personnel excluding three outliers of zero and one of 690mrem 414 mrem

Others

UNIT	# PERSONNEL LISTED	# WITH BADGE READINGS	AVERAGE DOSE (mrem)
H&S Co.	724*	151*	281
75 mm Pack How Btry	91	36	278
MAG-36			
H&MS-36	77	0	--
HMR 362, 363	164	13	290
MAG-15			
VMA 223, 224, 323	313**	19	231
VMF(N) 542	4	4	35
MASS-3	42	18	227
Totals	1415	241	

Average Film Badge Reading 261 mrem
Average of 125 Readings between 300 and 500 mrem 406 mrem

* May include members of the 75 mm Recoilless Gun Platoon, 4.2" Mortar Platoon, and the Brigade Helicopter Support Unit, which were units of the 3d MCPAEB but are not separately identified in the listing.

** Except for 24 pilots, this unit was not at Desert Rock and did not actively participate in Shot BEE.

The readings closely approximate a normal distribution around this mean with a standard deviation of 48 mrem. Note, however, that there are no badge readings for company C. Since there are no indications of any variations from the exercise activities described in Section 2, it is concluded that the film badge doses for Company C personnel are within the same range as those of the other three line companies.

The data shown in the table for the other units includes a much larger range of variation. This is as expected since other units, such as the Headquarters and Support Company, had a variety of other assignments (e.g., transportation supply, communications) which would result in activities and exposures significantly different from those of the rifle companies. The distribution of these film badge readings is, in fact, bimodal with a cluster of 75 readings between 0 and 50 mrem and another of 125 readings between 300 and 500 mrem. Of the remaining 41, there are 29 scattered between 50 and 300 mrem and 7 above 500 mrem. The five highest readings are for three officers and two sergeants from MAG-15, all with readings of 870 mrem, which correlate closely with the 830 $\pm$ 350 mrem for observers at Shot BEE (Reference 6). The 125 film badge readings between 300 and 500 mrem are approximately normally distributed around a mean of 406 mrem which compares closely with the average of 414 mrem for the line companies. It is concluded that these are representative of the members of this group who were assigned to Serials 1 through 6 (Table 2-1) and whose activities and exposures were therefore the same as the rifle companies.

Thus, there is reasonable correlation of the calculated total doses of $570\ ^{+350}_{-270}$ mrem for Serials 1 through 4 and $590\ ^{+350}_{-270}$ mrem for Serials 5 and 6 with the dosimetry records which show a mean film badge reading of the line companies of 414 mrem as well as an average film badge reading of 406 mrem for an additional 125 members of other brigade units. The large spread of film badge readings of the remaining 116 film badge records of the 3d MCPAEB are probably due to the variety of individual assignments, activities, and exposures involved.

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